U.S. Mines, Bur. of

Technical Paper 152

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

THE INFLAMMABILITY OF ALUMINUM DUST

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no. 152
ENGINEERING

BY

ALAN LEIGHTON

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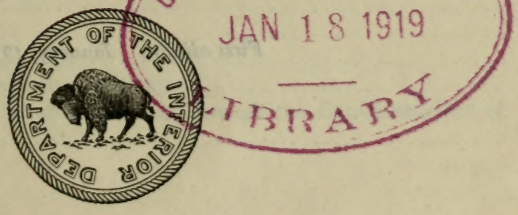

WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

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First edition. January, 1919.

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A STUDY OF THE INFLAMMABILITY OF ALUMINUM DUST.

By Alan Leighton.

INTRODUCTION.

Aluminum dust burns quietly when in a pile, but if this pile be disturbed in such a manner as to raise a cloud of the dust into the air the burning takes place with explosive violence. If a dust cloud already formed that has a density within the explosive limits be ignited, a violent explosion results. As several disastrous explosions of this dust have happened in manufacturing establishments, the Bureau of Mines has thought it worth while to investigate the physical and chemical properties of the dust with especial regard to inflammability and to the problem of extinguishing fires and of minimizing the force of explosions once started.

REVIEW OF AVAILABLE LITERATURE.

Most authors, in discussing the physical and chemical properties of aluminum, deal only with properties of the metal in mass and have little to say of the properties of the dust. As the dust will probably show all the properties of the mass to a more marked degree, reactions too slow to be observed in the mass may be very violent in the dust.

Stockmeier[a] says that aluminum powder is ordinarily stable under friction, but that gentle rubbing after the addition of potassium chlorate causes it to explode violently. If the powder be shaken in a flask with air, it can readily be exploded by an electric spark.

According to Stockmeier, aluminum powder is markedly hygroscopic and frequently contains as much as two to three per cent moisture. At temperatures above 30° C. water is decomposed into hydrogen and oxygen by aluminum powder. Although he shows that as much as 45 to 52 liters of gas could theoretically be liberated in the ordinary aluminum mill, he was unable, in experiments under seemingly the most favorable conditions, to liberate more than one-quarter of the theoretical amount. Stockmeier says this amount under the usual conditions would not be dangerous, but notes that an increase

[a] Stockmeier, H., Ueber die Ursachen der Explosionen bei der Bereitung des Aluminiumbronzepulvers Ztschr. Untersuch. Nahr. u. Genussm., Jahrg. 2, January, 1899, pp. 49–61. Abstracted in Jour. Soc. Chem. Ind., vol. 18, 1899, p. 280. Über Explosionen in der Aluminiumbronzefarben-Industrie: Chem. Ztg., Jahrg. 30, 1906, pp. 580–581. Abstracted in Jour. Soc. Chem. Ind., vol. 25, 1906, p. 639.

in the temperature of the wash water during washing sometimes gives rise to violent evolution of gas. Here the danger of explosion may be very great.

Stockmeier also says that he has observed large flames of burning hydrogen when water has been employed to put out a fire in aluminum dust, and that some explosions have been caused by sparks from broken fans in ventilating systems.

He suggests a few precautions to be observed:

1. Keep dust dry.
2. Keep rooms at even temperature—presumably to prevent condensation of moisture and to prevent conditions favorable to the generation of large static charges of electricity.
3. If the dust begins to darken (oxidize), immediately remove it from the room where other dust may be present, and thoroughly ventilate the place to remove any hydrogen that may have been generated.
4. Use no naked lights.
5. Keep the air as free as possible from dust.

In another paper Stockmeier[a] says that he determined the ignition temperature of ordinary aluminum dust powder to be between 480° and 490° C., and that the finest powder may be ignited at 230° C., but does not describe the method of obtaining these values.

Kohn-Abrest,[b] in a paper on the oxidation of aluminum powder, states that if the powder be heated for 10 minutes in a tube open at both ends, no sign of oxidation is observable unless the temperature be raised above 400° C. The rate increases as the temperature is raised to 625°, is then constant to 750°, increases again to 1,000°, and is constant at 1,200°, when no further reaction appears to take place. The metal begins to lose its luster at 500° C.

Richter[c] traces several dust explosions to electric sparks proceeding from brushes used in polishing, elevating, etc. He recommends that the brushes be made of aluminum wire, grounded, and that if brushes other than wire be used, grounded wires be included in them and they be dipped in a weak sulphuric-acid solution to accelerate their conductivity. In this way any static electricity generated by friction will be removed.

C. Edelman[d] experimented on the electrical conductivity of the dust and found that at low voltages it is a nonconductor, but that

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a Stockmeier, H., Über die Explosionen in der Aluminumbronzefarben-Industrie: Ztschr. Angew. Chem., Jahrg. 19, Oct. 5, 1906, II, pp. 1665-1668.

b Kohn-Abrest, Sur différents états d'oxydation de la poudre d'aluminium: Compt. Rend., July 31, 1905, t. 141, pp. 323-324. Abstracted in Jour. Soc. Chem. Ind., vol. 24, 1905, p. 906.

c Richter, M. M., Über die Ursache und Verhütung der Explosionen in der Aluminumbronze-Industrie: Chem. Ztg., Jahrg. 30, Apr. 11, 1906, I, pp. 324-326; Jahrg. 32, Feb. 8, 1908, I, p. 136. Abstracted in Jour. Soc. Chem. Ind., vol. 25, 1906, p. 430. Chem. Abs., vol. 2, 1908, p. 1491.

d Edelman, Otto, Über die Ursache und Verhütung der Explosionen in der Aluminumbronze-Industrie: Chem. Ztg., Jahrg. 30, Sept. 22, 1906, II, pp. 925-926 and pp. 921-952. Abstracted in Jour. Soc. Chem. Ind., vol. 25, 1906, p. 1099.

above a pressure of 350 volts it conducts. From this he deduces that the dust is a good conductor as regards static electricity, so that little difficulty should be encountered in properly grounding all machinery, and that as the dust coats the surfaces of all machines there is little opportunity for the accumulation of large local charges on them.

Zink [a] disputes a statement made by Richter in one of his papers that the dust is not explosive without the presence of some inflammable gas. He also believes that the chance of hydrogen being evolved when sulphuric acid is used on brushes is enough to make the practice absolutely dangerous. Zink considers that carbide probably is present in the dust and suggests that this may be a source of trouble. He recommends that all mills be kept closed with a covering permeable to gases, which would blow out to relieve the pressure in the event of an explosion. These safety devices should connect with the outer wall of the building in such a way as to direct the force of the explosion out of doors. This does not seem a good suggestion, because such a large opening is needed to relieve explosions as violent as those resulting from the ignition of aluminum dust.

PRELIMINARY EXPERIMENTAL WORK.

The author found that aluminum dust laid as a train on a soft wood board could be ignited by short circuiting a current of electricity through it; that when water was dropped on the burning pile a violent puff resulted; and that if the dust were spread on composition board or an iron plate, it fused with the passage of the current and burned locally, but did not burn of its own accord.

It was found also that if a large iron bar was heated to a dull red heat (approximately 600° C.) aluminum dust sprinkled on it melted and stuck to the rod, but did not ignite. If coal dust was blown against the rod from the injection jet of the Clement-Frazer apparatus (used in tests of coal dust as described on p. 10), a partial ignition resulted, but under similar treatment there was no visible ignition of the aluminum dust.

Evidently the ignition point of the aluminum dust is above that of the coal dust, but the definite ignition temperature and the smallest concentration of dust particles necessary to propagate an explosion remain to be determined.

In regard to the burning of the dust on wood, it is quite evident that the heat distilled inflammable products from the wood, which greatly accelerated the burning, and that perhaps there was enough moisture in the wood to take part in the reaction.

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[a] Zink, R. J., Über die Entstehung und Verhütung von Aluminiumstaubexplosionen: Chem. Ztg., Jahrg. 35, Dec. 12, 1911, pp. 1370-1372. Abstracted in Jour. Soc. Chem. Ind., vol. 31, 1912, p. 30. Chem. Abs., vol. 7, 1913, p. 730.

J. W. Paul, in an unpublished report on the New Kensington disaster says that the fire communicated to some boards which presumably were coated with dust, and that the fire proceeded vigorously from that place.

In view of the above it seems advisable that metal sheeting or some fireproof material be used on the inside of buildings in which the dust is to be handled. Of course fireproof construction is desirable wherever inflammable substances are to be handled, but there seems to be a special need for it where a room is liable to become covered with aluminum dust.

THE MATERIAL.

As prepared, the aluminum dust of commerce is finely divided aluminum metal with a coating of oil,[a] usually stearine or some similar material. This coating evidently serves to prevent oxidation in air and to protect the metal particles from the action of moisture, as it is stated that the product loses its luster if no oil be added.

PROPERTIES AFFECTING EXPLOSIBILITY.

DENSITY.

Aluminum dust is so light that it is easily blown about a room, and as the workmen seldom take precautions to prevent this the workrooms are soon coated with the dust. Evidently all apparatus should be inclosed to prevent loose powder from being blown into the air.

If a fan-suction system is employed to carry away the dust, it is advisable to consider the introduction of a dust precipitator a short way from the machine to collect the dust and to minimize the risk of an explosion at the bin or in the pipes. Explosions in flour mills frequently start at the fan and spread through the system to the dust room, where conditions for a violent ignition are excellent.

The ventilation systems employed at the factories where the explosions occurred seemed to be designed to keep the air in rapid motion; hence they helped to suspend the dust in the rooms. There was also no device to collect the dust, and with the constant circulation of air more and more dust accumulated in the system and was thrown into suspension in the room. This must be avoided.

HEAT OF FORMATION AND SPECIFIC HEAT.

Attention is called to the heats of formation of most aluminum compounds. For example the heat of formation of aluminum oxide is 392,600 calories as compared with 103,100 calories for the

[a] Guillett, L., Manufacture of aluminum foil and powder. Rev. Metall., 1912, pp. 147–159; also Jour. Soc. Chem. Ind., vol. 6, 1912, p. 730, and vol. 31, 1912, p. 339.

formation of carbon dioxide. It is thus evident that a large amount of heat is liberated when aluminum burns and the reaction is, of course, correspondingly more violent than the explosion of a coal-dust cloud.

Also, aluminum has a high specific heat. This property of the metal may explain why so much trouble was encountered in trying to ignite clouds of aluminum dust with small sources of heat, as described elsewhere in this paper. The quantity of heat that would be stored in a red hot pile would account for the violent reaction that takes place when water is poured onto the pile.

OIL COATING.

There may be danger in the oil coating. H. M. Wolflin, of the Bureau of Mines, in an unpublished report on the explosion at Berkeley, Cal., says:

"At the present time the plant is feeding about 0.67 per cent of an oil of low flash point into the ball mills with the granulated aluminum. It formerly used as much as 2 per cent and had considerable trouble with spontaneous heating." Hence it would seem that the amount of oil added should perhaps be just enough to insure protective action and not enough to cause, on standing, conditions that favor spontaneous combustion.

ACTION OF MOISTURE.

Stockmeier's observations indicate that moisture is most dangerous if the dust be heated at all. Mr. Wolflin says that the temperature in the ball mills often reaches 135° to 240° F. (57° to 116° C.), which is well above the temperature (30° C.) at which decomposition is said to start.

As the dust is hygroscopic, the air in the room must be kept dry, and here, again, a proper ventilating system is important.

If the dust starts to burn from spontaneous heating or other causes, it is very dangerous to put water on the mass; burning hydrogen is liberated immediately when the dust is thrown into the air and a terrific explosion usually results. In one case on record a violent explosion resulted from pouring molten aluminum through a screen into a bucket of water. Although such pouring had been done for several months without mishap, conditions on this particular occasion were evidently favorable for the liberation and ignition of hydrogen.

CONDUCTIVITY.

Although the conductivity of aluminum dust is low at low voltages, the resistance breaks down at a difference of potential of approximately 300 volts and the dust then becomes a good conductor. As the

dust clouds are readily ignited by an electric spark, all apparatus must be completely grounded. As potential differences of much more than 300 volts are necessary for sparking, the dust itself makes an excellent conductor and greatly favors the discharge of any static electricity formed.

The breaking of machinery, the poor lubrication of bearings, and the striking of metal parts may all cause spark formation, therefore tools of the softer metals should be used wherever possible; also the machinery should be kept in good condition and inspected regularly.

SPONTANEOUS COMBUSTION.

Spontaneous heating often takes place in piles of dust exposed to air, and evidently such heating is accelerated by an excess of oil. The remedies for such heating are self-evident; first, to prevent the collection of the dust, and, second, to regulate the amount of oil.

EXPLOSIBILITY.

The following work was conducted to determine the approximate ignition temperature of aluminum dust clouds as is done similarly with coal dust in the Clement-Frazer apparatus.[a] Difficulties were encountered which made it impracticable to do any more than get an approximate value.

PROCEDURE.

In making explosibility tests of coal dust Clement used as an igniting element a coil covered with sheet platinum. To measure the surface temperature of this coil a thermocouple junction was fused directly to the sheet. To determine the ignition temperature of aluminum dust with this apparatus the platinum surfaces must be replaced with some material with which the hot aluminum will not alloy.

Therefore a coil was made having as an igniting surface a heavy coating of alundum cement. In this cement the thermocouple for temperature measurements was buried. After the apparatus was assembled tests were made to determine the surface temperatures reached when definite currents were passed through the coil for a standard length of time. From these figures a temperature-current curve was plotted, and the thermocouple was removed before any aluminum dust was tested.

According to the method of procedure employed in operating the Clement-Frazer apparatus, 50 and 100 mg. of aluminum dust were successively shot up against the coil, the range of the coil temperatures being 800° to 1,200° C. Under these conditions the aluminum dust did not ignite.

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[a] Clement, J. K., and Lawrence, J. N., Laboratory determination of the explosibility of coal dust and air mixtures: Tech. Paper 141, Bureau of Mines, 1917, p. 6.

At a coil temperature of 800° C. coal dust gave off some smoke, but no fl me was seen. At 900° C. coal dust gave a small flame, and at higher temperatures a good ignition.

If the aluminum dust was mixed with coal dust and shot up against the coil at a temperature of 900° C., the flame produced in the coal dust was brilliantly colored by the aluminum powder. This result seems to indicate that the ign tion temperature of aluminum dust is perhaps as low as, if not lower, than that of coal dust, and also that the coil in the apparatus has a heat capacity too low to heat the dust above its ignition temperature in the short time that the dust and coil are in contact.

In order to determine the effect of a body of greater heating capacity than the core of the Frazer apparatus, a small clay incinerating dish was placed in the muffle furnace. As soon as the temperature of the muffle reached 500° C. the dish was removed quickly and about 10 grams of the dust was poured into it from a small scoop; no ignition was obtained. Coal dust did not ignite at this temperature, but gave off much volatile matter as it struck the dish, and the dust that settled in the dish finally began to glow. This procedure was repeated with every 50° rise in the furnace temperature, and at 800° C. the aluminum cloud ignited with a brilliant flash. At this temperature and at 840°, the highest temperature employed, the coal dust cloud did not ignite. The volatile matter distilled rapidly, and the coal finally burned. The result for coal dust was anticipated, as the temperature of the dish was not as high as the so-called critical temperature of the coal as established by the Clement-Frazer apparatus.

CONCLUSIONS.

Although these experiments do not show the exact conditions under which an ignition of the aluminum dust is obtained, they do show that it may ignite at temperatures even lower than those necessary for the ignition of 200-mesh standard Pittsburgh coal dust; also more heat is needed to ignite aluminum dust. The dust used in these tests was a commercial product labeled "aluminum bronze."

FIRE EXTINCTION.

Evidently water is worse than useless to extinguish a fire in aluminum dust. It is positively dangerous.

Attempts have been made to use carbon tetrachloride as an extinguisher, but thisw as found to be as bad as water. Probably, as suggested by A. C. Fieldner, carbon tetrachloride and aluminum form $AlCl_3$ in the presence of heat, thus liberating carbon to unite with the oxygen. The heat liberated by the formation of $AlCl_3$ in

excess of that taken by the breaking up of CCl_4 is approximately equal to the heat of combustion of carbon to CO_2.

If a fire in a gob of aluminum dust be isolated, a crust of aluminum oxide forms over the surface and smothers the fire. This method of extinguishing a fire is evidently dangerous, for any accident that raised the pile into a dust cloud would immediately cause an explosion.

In one of the factories handling aluminum dust, oil is poured onto the fire until the oil burns and the aluminum fire is smothered, whereupon carbon tetrachloride is used to extinguish the fire in the oil.

In another factory sand is poured carefully on the pile, the pile isolated, and the fire smothered in this way. It appears that fine shale dust, such as is used in dusting coal mines to prevent explosions, may be used to advantage, as the shale makes a denser cover that excludes the air more completely. Also the dust is not free flowing, and there is less danger of any movement in the pile tending to raise a cloud, and if through accident a cloud were raised there might possibly be enough of the inert dust in the air to prevent a disastrous explosion.

An investigation of the use of dry sodium carbonate in the extinguishing of these fires would be of interest. A large amount of heat is needed to decompose sodium carbonate, and the carbon dioxide freed would help smother the fire. It is not believed that the resulting sodium oxide would be dangerous, as aluminum compounds can be reduced with either sodium or potassium.

Any liquid used in fighting the dust fires must have a low surface tension in order that the dust may be wetted. Since practically all such liquids as alcohol, etc., are very inflammable, it seems difficult to conceive of any wet method to use.

SUMMARY OF PRECAUTIONS TO BE OBSERVED.

VENTILATION.

Use a ventilating system that will not raise loose dust into suspension nor keep it in circulation.

Use a system supplying dry air at a fairly even temperature. See that the volume of air supplied is enough to remove quickly any hydrogen from the room.

MACHINERY.

Have machinery well grounded, well cared for, and properly oiled.

Use tools of soft metal as far as practicable.

Have machinery inclosed as far as possible.

Use vacuum dust-collecting devices over machinery likely to spread dust.

GENERAL PRECAUTIONS.

Use no naked lights.

Isolate dangerous processes in separate buildings.

Avoid wood construction as far as possible.

FIRE EXTINCTION.

Avoid use of liquids in putting out fires, except, perhaps, oil, with subsequent use of carbon tetrachloride.

Use sand, or preferably shale dust.

Investigate use of sodium carbonate.

ACKNOWLEDGMENTS.

Besides the information obtained from the literature on aluminum dust the author acknowledges the valuable suggestions in the unpublished reports on the New Kensington (Pa.) disaster, by S. P. Howell and J. W. Paul. Mr. E. Blough, chief chemist of the Aluminum Co. of America, very kindly furnished the Bureau of Mines with a number of the references quoted.

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